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The NIST Manufacturing Engineering Laboratory: Assisting U. S. Aerospace Manufacturing Through Measurements and Standards

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Additional information about MEL and the programs summarized in this paper can be found at the MEL website, located at www.mel.nist.gov.

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Introduction

This paper discusses how the Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) promotes a healthy U.S. aerospace manufacturing sector by developing and applying measurements, standards, and infrastructural technology. The paper articulates MEL's current and potential future roles in assisting this key U.S. manufacturing sector with respect to technological disciplines associated with metrology, manufacturing processes and equipment, and systems integration and interoperability.

Background

NIST is a non-regulatory agency of the U.S. Department of Commerce's Technology Administration. Established in 1901 as the National Bureau of Standards, NIST strengthens the U.S. economy and improves the quality of life by working with industry to develop and apply technology, measurements, and standards. Global technology and market changes are demanding U.S. shifts in federal research and development (R&D) strategies, and NIST plays an important role in making investments for long-term economic growth. NIST focuses on tasks vital to the country's technology infrastructure that neither industry nor the government can do separately.

Among its portfolio of major programs, NIST operates a series of Measurements and Standards Laboratories that provide technical leadership for the nation's measurement and standards infrastructure and assure the availability of needed measurement capability to promote the U.S. economy and public welfare. The NIST Measurements and Standards Laboratories function and provide services as the U.S. National Measurement Institute (NMI). This is a role that is mandated by Congress to serve as the country's primary standards laboratory, realizing and disseminating traceability to the seven basic *Systeme Internationale d'Unites* (SI) units of measure, along with their derived units, that are used in the conduct of commerce. Efforts of the NIST Labs are planned and implemented in cooperation with industry, and they are focused on infrastructural technologies, such as measurements, standards, evaluated data, and test methods. The benefits from such enabling technologies typically spread across entire industries, and individual companies cannot recover the investments needed to produce them. NIST Laboratories provide a wide array of critical services, and they conduct vital enabling functions for the U.S. economy that wouldn't otherwise exist. The Manufacturing Engineering Laboratory (MEL) is one of the seven NIST Laboratories.

The mission of MEL is to satisfy the measurements and standards needs of the U.S. discrete-parts manufacturers in dimensional and mechanical metrology and in advanced manufacturing technology by conducting R&D, providing services and participating in standards activities.[1] MEL strives to promote a healthy U.S. manufacturing economy by solving tomorrow's measurement and standards problems today.

MEL is organized into five divisions, which are described on the following page:

- The Precision Engineering Division (PED) conducts R&D in precision-engineered, length-metrology-intensive systems in both measuring and production machines and instrumentation. PED realizes and disseminates traceability to the SI unit of length, the meter. PED delivers to industry and other government agencies important length-related measurements, standards, and technology services that support U.S. manufacturing's products and processes.

- The Manufacturing Metrology Division (MMD) conducts R&D in the realization and dissemination of SI mechanical units. MMD develops methods, models, sensors, and data to improve metrology, machines, and processes for manufacturing. MMD also provides services in, and leads in the development of national and international standards for mechanical metrology, machine metrology, process metrology, and sensor integration.

- The Intelligent Systems Division (ISD) works with industry, universities, and other government agencies in the development of new measurement techniques and standards for intelligent machine systems, robots, and automated manufacturing systems. ISD focuses on providing a theoretical framework for the development of interface standards and performance measures for intelligent systems. ISD also develops engineering guidelines for the design and implementation of intelligent control systems for a wide variety of applications.

- The Manufacturing Systems Integration Division (MSID) promotes the development of technologies and standards that lead to the implementation and interoperability of information-intensive manufacturing systems. Application areas where MSID focuses its efforts include engineering design, process planning, production planning and control, and enterprise integration.

- The Fabrication Technology Division provides fabrication support services for instruments and devices required by researchers from MEL and other NIST laboratories.

Through its research and services, MEL sustains a solid record of helping the U.S. aerospace industry, as well as many other manufacturing industries, successfully compete in the global marketplace. Manufacturers employ MEL research results, test methods, software conformance tests, calibration services, and measurement tools. Aerospace and other manufacturers collaborate with MEL on technical projects, standards development, and testbed-based research, both on an individual basis and as members of industrial consortia. In addition, MEL plays a key role in fostering inter-company cooperation and industrial adoption of strategically important manufacturing and computing hardware, equipment, and software standards.

MEL helps companies to design more collaboratively, machine more accurately, assemble more precisely, organize more efficiently, use information more productively – in a phrase, to compete more effectively.

MEL Customers and Industries Served

MEL research and services are primarily directed toward the benefit of the discrete-parts manufacturing sector. This sector represents a large portion of the U.S. manufacturing economy, and it generally includes those manufacturers who produce discrete products, meaning individual parts or part pieces. MEL's activities also tend to gravitate toward research and services that address the needs of mechanical and electro-mechanical product manufacturers.

For example, MEL work on characterizing and controlling machining processes enables manufacturers who employ machining and material removal operations to improve dramatically their tools, processes, and products. Efforts in the area of intelligent machines and systems are accelerating the trend toward open systems architecture and intelligent manufacturing. These efforts improve the ease by which systems can be integrated, and they are being applied to machine tools, robotic and autonomous systems, metrology instrumentation, and other equipment upon which U.S. manufacturers widely rely. Other efforts that focus on the interoperability of manufacturing systems at the factory and extended enterprise levels increase the ability of manufacturers to implement information-rich systems.

MEL has three types of customers:

1. customers that receive direct assistance from MEL,
2. sponsors outside of NIST who fund MEL work, and
3. oversight bodies who assess or evaluate the impact of MEL work.

These customers represent industry, government, academia, standards organizations, consortia, technical societies, and the public. They include users of MEL services and products, participants in MEL programs, and benefactors from MEL results.

MEL management is constantly faced with the need to establish priorities about which customers MEL should serve. Questions of where and how MEL should invest and apply its resources and focus its programs are growing more and more important as the recent NIST budget environment has tended to be characterized by relatively flat Congressional appropriations. Several methods and tools are used to assist in this prioritization process, and MEL endeavors to conduct rigorous strategic planning on an annual basis. The MEL strategic planning process addresses both short-term and long-term issues facing the Lab. The implementation of MEL's strategic plan is a living, continuous process that occurs throughout each year.

MEL conducted a strategic planning exercise recently with the assistance of professionals from the NIST Economic Assessment Office. The aim of the exercise was to identify the classifications and characteristics of the specific manufacturing sectors that fall into what is considered to be "discrete parts manufacturing industries."[1] This study revealed that two manufacturing sectors stand out both in size and the extent to which they contribute to the U.S. gross domestic product.

These two sectors are the aerospace and automobile manufacturing sectors.

These results have proven valuable to MEL for a number of reasons, including the following:

- MEL has conducted programs for many years in partnership with and technically directed toward the systems, technologies, and processes used by the aerospace and automobile sectors.
- MEL programs intensively focus their efforts on producing results that contribute to the production of outcomes that have broad impact across industry. As such, MEL tends to apply its resources to the conduct of research, provision of measurement services, and participation in standards activities that impact those sectors within discrete part manufacturing that are likely to have the greatest impact on the U.S. economy. According to this sector classification study, two obvious target sectors are aerospace and automobile.

It should be noted that the U.S. aerospace and automobile industries are by no means the only two industries that MEL serves. MEL programs address the needs of a broad array of other U.S. industries that conduct discrete-part manufacturing as well. Among such industries are the producers of heavy equipment, machine tool manufacturers, shipbuilders and the ship repair/conversion industry, semiconductor and microelectronics manufacturers, instrumentation manufacturers, and others.

MEL AND THE AEROSPACE INDUSTRY

With recent positive trends in the health of the global economy, world air traffic has increased. The U.S. aerospace industry has consequently found itself challenged by growth like never before to seek ways to improve manufacturing processes and production time. The NIST MEL conducts a number of technical programs that offer a variety of technical assistance to U.S. aerospace firms to enhance their competitiveness in the global marketplace.

MEL Program Focus Areas

MEL technical programs develop and apply measurements, standards, and advanced manufacturing technology. In performing these functions, MEL programs are designed and conducted in close connection to, and typically in partnership with, U.S. industry.

MEL programs can be described as applying to the following technology domains:

- Dimensional and mechanical metrology
- Manufacturing processes and equipment
- Systems integration and interoperability

These three technology domains represent one way in which MEL technical work can be classified in terms of major themes. It is not intended that these themes are or should be a representation of the structure of MEL's organizations or programs – neither in 2001, or

in the near future. They are offered for the purposes of this text as one way to describe technical foci of MEL work.

The year 2001 MEL technical programs that are relevant to U.S. aerospace manufacturing are described in the following sections, and they are grouped according to their address of these three technology domains. These groupings are provided for purposes of brevity. It is important to note that several MEL programs are multi-disciplinary in nature and as such address more than one of these domains. MEL technical programs may also address certain technology issues from domains not included above, but these groupings represent major focus areas of MEL.

The following sections provide descriptions of the technical goals and objectives of MEL's various aerospace manufacturing-relevant programs. A synopsis of how each program specifically addresses the needs of the aerospace industry can be found in the table contained in this document's Summary section.

Dimensional and Mechanical Metrology

The manufacture of airplanes, aerospace vehicles or other complex products requires thousands of different measurements to be made and repeated. This requirement spans the lifecycle from initial design to retirement from service. MEL researchers offer measurement standards and calibrations, and perform research that assist in addressing measurement problems and ultimately in assuring and assessing the quality of manufactured parts and materials. MEL activities in these areas focus on the performance of its NMI role for the country, serving as the country's primary standards laboratory for dimensional and mechanical metrology. This role includes an assignment to realize and disseminate traceability to the basic SI units of length – the meter – and of mass – the kilogram. This also includes realization and dissemination of units derived from the SI unit of mass, including force, sound pressure, acceleration, shock, and ultrasonic power.

The following MEL programs relate to dimensional and mechanical metrology.

Engineering Metrology

This program (1) provides dimensional measurement services, (2) develops new dimensional measuring techniques to address changing industry needs, (3) disseminates metrology knowledge, and (4) participates in national and international standards activities. The program includes a variety of length and geometric measurements of objects with characteristic dimensions that range from a fraction of millimeter to more than a meter.

This program supports national and international manufacturers, research and calibration facilities, standards writing organizations, and academia. The program strives to address, efficiently and effectively, the needs of its customers, which includes several aerospace manufacturers. These customer needs fall into three categories: (1) traceable measurements and standard reference materials with the lowest attainable uncertainty, (2) development of new techniques to improve and extend measurement capabilities, and (3) the latest, most accurate technical guidance on measurement related issues.

The improvement of gage block calibrations for AFMETCAL, the Air Force Metrology and Calibration Program, is one example of how this program assists the U.S. aerospace industry. MEL and AFMETCAL, which is located at Newark Air Force Base in Heath, Ohio, recently worked together to establish at AFMETCAL the same systems and procedures that are used at NIST for mechanical calibrations of gage blocks. Gage blocks are basic reference artifacts used by the Air Force, as well as many aerospace manufacturers, to establish dimensional traceability to the SI unit of length, the meter. Such traceability is a fundamental and critical building block upon which quality assurance systems are established for manufacturing and measurement processes. The new gage block measurement system allows AFMETCAL to calibrate gage blocks with much greater efficiency, while still achieving very small measurement uncertainties. Prior to this effort, AFMETCAL could achieve small uncertainties only through the use of static interferometry, a difficult and time-consuming measurement process. Most gage block sizes can now be calibrated with less than 50 nm uncertainty, a result that is difficult to achieve with mechanical calibration.

Large Scale Metrology

Large-part manufacturing industries require ever-decreasing tolerances. Many large-scale parts, even in high technology applications, lack interchangeability due to dimensional variation. For example, large commercial aircraft may require more than a ton of shims to complete assembly. This increase in weight can result in additional operation costs approaching $1 million per year per plane. Also, replacement parts typically must be custom-made to achieve proper dimensional alignment. These dimensional metrology problems result in increased pollution, component costs, and operating costs, as well as increases in down time needed for maintenance due to custom fitting.

Large-scale coordinate metrology makes a substantial contribution to reducing these problems associated with the inability to meet part tolerances during part manufacture and assembly processes. By providing enhanced machine tool capability and a better understanding of in-process feedback for more accurate production and assembly, as well as post-process measurement for continuous process improvement, it is possible to reduce or eliminate waste, rework, and low quality parts. Unfortunately, large-scale coordinate metrology is a relatively neglected field of metrology that lacks, among other things, standards and artifacts for characterizing the metrology instrumentation and methodologies for obtaining the best performance from these valuable metrology tools.

This program provides dimensional measurements and measurement research on the scale of one meter or larger. These efforts are primarily focused in three areas: coordinate metrology with linear axis coordinate measuring machines, coordinate metrology using frameless coordinate measuring systems (theodolite systems, laser tracker systems, or laser ranging systems), and machine tool metrology for emerging technologies such as parallel actuated machining systems. The initial development of laser tracker technology occurred at NIST in conjunction with activities of the predecessor to the current Large-Scale Metrology Program.

Large-scale coordinate metrology problems are addressed on two major fronts in this program: (1) developing national, international, and Department of Defense (DOD) standard specifications for these coordinate metrology instruments; and (2) conducting research into performance issues and subsequent artifact development in support of these standardization efforts. NIST staff members working this program are actively involved on both the American National Standards Institute (ANSI) and the ISO standards developing bodies in the area of performance assessment of large-scale coordinate metrology instruments.

Mechanical Metrology

This program provides U.S. industry, federal, state, and local governments, and the scientific community with best-in-the-world class measurement services and access to the top of the traceability chain for the mechanical quantities of mass, force, sound pressure, acceleration, shock, and ultrasonic power.

The program realizes and/or maintains the national standards for mechanical quantities and continuously seeks to improve its facilities. These facilities include a world-class clean room mass laboratory with tight environmental controls, a world-class force laboratory with six deadweight machines that generate discrete forces over a range of 44 N to 4.448 MN, a 450 m^3 anechoic chamber, and other specialized laboratories and equipment. The program strives to provide timely and accurate physical measurement services, and it performs short-term development to meet customer and standards needs.

An example of the type of assistance this program provides the U.S. aerospace manufacturing industry involves the NIST force calibration facilities. These facilities include a unique deadweight stack of 1-million-pounds of weight that are used as references to allow NASA and other aerospace organizations to reliably measure propulsive force. In fact, the origin and need for this facility goes back to the original space race of the 1950s and 1960s.

Shop Floor as a National Measurement Institute (NMI)

This program develops the means to allow U.S. manufacturing firms to meet the global-market requirement for "new traceability" by making task-specific measurements effectively and economically on the shop floor that:

- realize the international standard of length without dependence upon calibrations made by NIST or any other NMI
- use measurement uncertainty to describe the expected variability in the measurement result
- approach the highest level of accuracy technologically attainable, without development by NIST of the task-specific measurement services or capabilities themselves.

The program aims to develop, validate, and propose for standardization an array of non-task-specific techniques. These would allow task-specific dimensional measurement on

parts in the manufacturing shop floor environment of a demonstrable uncertainty and traceability to the SI unit of length without recourse to, or dependence on:

(1) provision by NIST of a task-specific measurement service, or
(2) development by NIST of a task-specific measurement capability, or
(3) development for testing by NIST of a task-specific measurement methods.

In essence, the results of this program will help U.S. manufacturers, especially the aerospace industry, demonstrate on the shop floor, measurement capability that has traditionally been performed only at NIST or other NMIs. There is a growing need for this precise measurement capability in the harsh manufacturing environment, and this need has been demonstrated by the interest and collaboration in the program by leading U.S. aerospace manufacturing companies.

Surface Metrology

This program is delivering to U.S. industry measurement services in surface and microform metrology of unimpeachable quality and of a variety that industry requires. Surface finish is a characteristic of a product that directly affects its function and is applicable to a wide array of industrial products ranging from roadways, ship hulls and propellers, motor vehicles, planes, and rockets, to microelectronics and optics. According to the "U.S. Industry and Trade Outlook 2000", the value of shipments by U.S. manufacturers in motor vehicles alone was forecast to be $225 billion in 2000.[2] For the microelectronics and aerospace industries, those figures were forecast to be $189 billion and $136 billion, respectively. Many functional surfaces of these products must be specified and measured for surface finish as well as for the dimensions of certain microscopic surface features. The functional properties affected by the surface finish include friction and wear, semiconductor integrity, optical imaging quality, and customer perception of quality based on appearance.

NIST calibrations and measurement research are critical to maintaining an accurate national measurement system for surface metrology as are NIST contributions to several standards committees to formulate mutually agreeable and meaningful measurement results. An important part of this system is accurate calibration of critical surface features such as the radius of hardness indenters for the metals industry or step heights and pitch spacings for the semiconductor industry. NIST calibrations are needed, for example, to support measurements of a variety of parameters including average and root mean square roughness, power spectral density of roughness, hardness indenter radius and cone angle, and feature heights and spacings in the semiconductor and data storage industries.

This program provides calibrations and services that support surface metrology and scanned probe microscopy. Work also occurs to apply the calculation of electromagnetic wave scattering to critical surface metrology problems. The program supports industry's efforts to develop national and international documentary standards in surface metrology and scanned probe microscopy. The program also provides standard reference materials having properties that industry cannot supply for itself, and it resolves methods divergences in surface measurements between different techniques, different laboratories, and different countries.

Manufacturing Processes and Equipment

There are thousands of processes involved in the manufacture of a product as complex as an automobile or and aircraft, and the manufacture of these products cannot be conducted in any type of volume capacity or degree of accuracy without robust and reliable equipment. MEL research is helping in several areas to make these processes and manufacturing equipment more accurate and more efficient.

The following MEL programs focus on manufacturing processes and equipment.

Metrology and Smart Systems for Manufacturing Equipment

This program provides methods, standards, and smart sensor systems to characterize, monitor, and improve the performance and health of equipment for the manufacture of discrete parts, with a focus on machine tools for material removal. The vision of this program is manufacturing equipment whose performance is known and assured through real-time self-characterization, self-diagnosis, and self-improvement to achieve zero unscheduled downtime and error-free execution of manufacturing operations.

The program addresses the needs of U.S. manufacturers, including aerospace companies, as they are faced with the challenge of intense global competition while moving toward more complex parts, closer tolerances, smaller batch sizes, shorter time-to-market, just-in-time production, more general-purpose equipment, and manufacturing that occurs on a more globally distributed basis.

Success in this environment requires accurate and reliable manufacturing equipment whose performance is known and guaranteed for a large variety of tasks and operating conditions. The ability of an aerospace manufacturing enterprise and its suppliers to meet these requirements largely determines the range and features of products that can be produced, the capability in which the first and every subsequent part meets specifications, and the efficiency and agility of the manufacturing process.

The program is working with several U.S. aerospace manufacturing companies to develop tools to enable design and manufacturing engineers to predict machine tool performance to ensure that parts can be machined to specification with a minimum of prototyping. This includes the development of information models, electronic data formats, database designs, and networking tools to facilitate the collection, storage, use, and exchange of machine tool data; as well as the development of methods and algorithms to predict the tolerances of machined parts from generic machine tool performance data.

The program is also revolutionizing the connectivity and utilization of sensors in metrology, manufacturing, and conditioned-based maintenance to enhance industrial capability and manufactured quality. This is viewed as critical by many leading manufacturers, including one major U.S. aerospace manufacture that plans to connect several thousand pressure transducers on the wing of a test plane to a single network, instead of discretely wiring each of them to multiplexers. This will dramatically reduce the thickness and complexity of wiring bundles.

Assisting and often leading the development of national and international standards in these technical areas is a large facet of this program. This includes participation and provision of secretariat services by program staff on several standards committees, including the Institute of Electrical and Electronics Engineers (IEEE) 1451 Standard for a Smart Transducer Interface for Sensors.

Predictive Process Engineering

This program develops the measurements and standards needed to characterize and specify manufacturing processes sufficiently well to ensure "first part, good part," which is one of the powerful visions espoused in current manufacturing roadmaps. Achieving this vision requires making the next logical step in a series of paradigm shifts in manufacturing product realization.

The 'golden era' of U.S. manufacturing (pre-1975) was defined by a linear process. Part designs were developed and then "lobbed over the wall" to manufacturing, which developed a process plan (implicit or explicit). After the part was made it was inspected - and likely rejected. Several iterations resulted in a process producing geometrically acceptable parts, sometimes.

Another control loop addressed functional criteria such as residual stresses and paint adhesion. The mid-1980s saw a new paradigm, the idea of in-process geometric measurement with feedback. In general, the measurements were process intermittent, and subsequent functional inspection resulted in some reject rate and some feedback to improve the process. At NIST, this paradigm was embodied in, and driven by, the Quality in Automation program.

"First part, good part" demands a different approach in many areas of manufacturing engineering. This program proposes a new paradigm in predictive manufacturing – "process characterization" leading to proactive quality assurance. The new paradigm is a shift from classical feedback quality assurance or optimization to model-based feed forward process design and quality control. Part design assumes knowledge of process specifications and generates, seamlessly, a process designed to produce the right part first time; there will be no prototyping. Feedback from process metrology improves the process model, the process specification, and the manufacturing process itself.

This program works with aerospace companies and other U.S. manufacturers to address the typical ad-hoc nature of current manufacturing process development. Process parameters, such as machining speeds, feed rates, and tool selection, are typically chosen by costly, trial-and-error prototyping, with the resulting solutions often sub-optimal. U.S. manufacturers tend to choose incorrect tooling for manufacturing processes very frequently, they usually do not use cutting tools at their rated cutting speeds, and they seldom use cutting tools to their full life capability. These sub-optimal practices are estimated to cost U.S. industry billions of dollars per year.

Pressure from international competitors is driving industry to seek more sophisticated and cost-effective means of choosing process parameters through modeling and simulation.

Optimal manufacturing performance requires sufficient understanding of the impact of individual parameters on the various levels of the control hierarchy, from the shop floor to the overall enterprise. This program seeks to develop the infrastructural foundations in the form of measurements and standards that will ultimately lead to the implementation of more optimal manufacturing processes.

Systems Integration and Interoperability

Computer controlled manufacturing processes and systems need to speak the same language. Computer-aided design (CAD) systems must be able to receive and transmit product data accurately between and within shops. CAD systems must be able to communicate efficiently with other computer-aided systems used throughout product and process development, including computer-aided manufacturing (CAM) systems.

Some of the real benefits of MEL work in the U.S. aerospace industry can be seen in small part by examining the impact of the development of the ISO 10303 Standard for the Exchange of Product model data (STEP). MEL played a major role in the development of STEP, dating back to its being a leader in the creation of Product Data Exchange Standard, the precursor to STEP. As an example of STEP impact, a major aircraft program of the U.S. Air Force has shown consistent cost savings since STEP was implemented, along with significant process savings in the manufacture of composite materials, and on tool design for CAD and CAM systems. STEP has also been incorporated into several U.S. commercial aircraft manufacturing programs. There has been significant timesaving in processing designs from engine suppliers using STEP, and in one major military aircraft program the time required to transfer bills of material data, averaging several thousand parts per night, has been reduced from weeks to minutes using STEP.

The following MEL work focuses on interfaces, architectures, and representation formats in an effort to improve the integration and interoperability of manufacturing systems. The results of this work can mean that U.S. manufacturers spend less time solving integration and interoperability issues and more time making their products.

Intelligent Open Architecture Control of Manufacturing Systems

This program provides measurements and standards needed to support a competitive market in intelligent control technology for U.S. discrete parts manufacturers, including aerospace manufacturers. Specifically, the program participates in industry efforts to standardize open architecture control for the machine tool, robot, and automated metrology equipment sectors. Each of these sectors produces equipment that is typically used in the manufacture of aerospace vehicles and platforms.

When possible, MEL identifies standardization efforts at their beginning, by working with industry and government agencies to identify and develop new manufacturing applications of intelligent control. The program continues by participating with industry groups to develop suitable architectures on which to base standardization. Program activities focus on validation, performance measures, standardization, and conformance tests.

Testbeds are established within the program for developing performance measurement techniques and validating architecture and interface standards. Standards validation work proceeds in collaboration with industry groups, during a lengthy period of interaction with members. This results in the publishing and dissemination of the architecture and interface specifications. Program participation culminates in the provision of conformance tests that can be applied by vendors, users, and third parties to maximize interoperability.

Several factors in today's manufacturing environment contribute to the need for the standardization of open architecture control. Globalization of manufacturing operations is creating new pressures for common programming and integration solutions from vendors around the world. Interoperability and programming problems are gaining increased attention as the associated costs continue to grow and become more known. Large users of automated equipment, especially aerospace and automotive companies, are working to coordinate their efforts to solve these problems. Finally, the commercial open architecture control market is relatively small but growing rapidly. These are all favorable conditions to allow the efforts of this program the opportunity to achieve significant impact.

Manufacturing Enterprise Integration

This program strives to enable on-the-fly integration of manufacturing business-to-business, or B2B, software applications using intelligent agents and shared semantics, thereby eliminating the need for interface specifications.

Manufacturing has changed dramatically over the last few years due to the pressures of globalization and the ubiquity of the Internet. Globalization has forced manufacturers, including aerospace companies, to seek partners, suppliers, and customers all over the world. The Internet makes it possible for manufacturers to actually link up with those partners, suppliers, and customers. However, the Internet is not enough. To turn possibility into reality requires instant integration of a myriad of enterprise-level software applications.

This research program seeks to provide a foundation for new measurements and standards that will enable this self-integration. This will eliminate the need for these specifications, saving billions of dollars for industry and generating a new role for NIST. The program researches the pursuit of systems interoperability with "lighter standards" that do not have to specify as much, or, even better, with translators and mediators that can dispense with many higher-level standards altogether. MEL works to develop the parameters, tests, and testbeds that help measure the quality and fitness of ontologies and mediators.

Software agents have become popular with the advent of on-line trading, where they often act as brokers. In manufacturing, including aerospace manufacturing, agents are software components that perform specific tasks relevant to some enterprise goal. They have been used to perform decision-making tasks, such as planning or scheduling, and control tasks, such monitoring manufacturing equipment. More recently, they have been proposed as brokers in B2B environments and information gatherers in e-commerce environments. In

the former, they will act as matchmakers between potential partners in a supply chain. In the latter, they will seek out suppliers of specific products, such as books or airlines, for individual customers. This program plans to use agents in yet another novel way. To this end, another focus area of the program is an agent-based system that manages the negotiation process required to achieve integration between software applications and the process required to achieve agreement on the meaning of the information they share.

Manufacturing Simulation and Visualization

This program strives to make the benefits of discrete-event manufacturing simulation affordable to a majority manufacturers, including companies from the aerospace industry. The program focuses on reducing the time and cost of model development and simulation system integration by 50 % through the identification, specification, prototyping, testing, and evaluation of data interfaces and methods for integrating manufacturing simulation and visualization applications with each other and with other manufacturing software. The program also focuses on the establishment of standard distributed simulation interfaces and component libraries.

Although several recent studies recognize the potential of manufacturing simulation and visualization, there are a number of technical and economic barriers that hinder the use of this technology. Industry expense for implementing simulation technology is much greater than the cost of computing hardware, peripheral devices, software licenses, and maintenance. Typically companies must factor in the cost of salaries and training for simulation and support staff, translation of existing company data, systems integration of applications, and development and maintenance of models. These costs are likely to be much greater than the initial acquisition costs for the simulation software and hardware.

The development of neutral data formats for simulation models is an area in which this program can have a major impact on the ease and cost associated with the implementation of manufacturing simulation and visualization, including such implementation by aerospace manufacturers. The program is uniquely positioned with its neutrality, expertise, and testbed capabilities to support industry in the development of these neutral component models, related simulation technology, and interface standards to integrate manufacturing simulation systems.

Top management of a number of simulation software vendors have already endorsed MEL plans to develop neutral vendor-independent formats for simulation-component models, and the program works closely with the U.S. defense industry and an international manufacturing effort as means to further assist program development and results. Near-term program activities focus on architectures, interfaces, and data models that will enable the development of vendor-neutral model libraries for simulation.

Standardized interfaces, component model libraries, and modeling techniques promise to reduce the cost and increase the accessibility of manufacturing simulation technology for U.S. industry. A major focus for the Manufacturing Simulation and Visualization program is the identification and specification of data interfaces for various manufacturing simulation applications

Product Engineering

This program develops information protocols for interoperability of computer-aided design (CAD) and product engineering systems. The program seeks to provide a basis for future standards in areas with high industry impact, focusing on the key issues that are emerging from the new collaborative product development paradigm. Specifically, the primary needs for the next generation of CAD-related software systems – systems that will be used in a widespread manner throughout the U.S. aerospace industry – include the following:

- interoperability among software tools,
- collaboration among distributed designers and design teams,
- integration of data and knowledge across the product development cycle (from design, to analysis, to manufacturing and beyond), and
- knowledge capture, exchange and reuse.

The R&D efforts of this program, ranging from specification and standards development to technology development and prototype implementation, strive to provide the foundation that will support the creation of next-generation product development tools. This program's results are therefore expected to increase the efficiency, effectiveness, capability and productivity of U. S. industry, including aerospace manufacturing companies.

Other Relevant Area: Information Technology Metrology

MEL also conducts research and provides services that are focused on issues associated with information technology metrology for manufacturing. This body of work develops and provides formal methods, reference artifacts, and testing services that is needed by U.S. industry, including aerospace manufacturers, for the continuous improvement of manufacturing software interoperability and information reliability. MEL pursues fundamental research efforts focused on test methods, testability, and quantified references. These will provide industry the resources it needs to develop quality standards and measure implementations.

MEL works to identify the elements common to individual measurement issues, to synthesize these common elements into the principles underlying rigorous testing approaches, and to codify these principles into a set of formal methods that can be applied over a wide spectrum of manufacturing problem domains.

As part of this effort, MEL identifies and enumerates types of software testing relevant to systems integration, including identifying how those testing mechanisms relate to one another. MEL also develops a lexicon of testing terminologies, investigates the methodologies and metrics relevant to systems integration testing and software behavior characterization, and develops best-in-class approaches. MEL staff perform the research necessary to create a measurement infrastructure for manufacturing information technology.

MEL is establishing a formal basis for the testing and analysis of standards-based software implementations. This work provides reference data for measuring software performance and accuracy, and it defines metrics and dimensional units for software measurement. Through this work, MEL provides U.S. industry, including aerospace manufacturers, suppliers, and their equipment and systems vendors, a scientific foundation that is used to improve the integration of software applications. The integration of these applications is critical to the manufacture of products ranging from aircraft and aerospace vehicles and platforms, to automobiles, to any number of other commercial or military items.

Summary

The NIST MEL conducts an array of leading-edge technical programs that are focused on anticipating and solving the measurement and standards needs of the U.S. discrete-parts manufacturing industry. The work summarized in this paper is conducted either in collaboration or in direct partnership with organizations from the U.S. aerospace manufacturing sector of the economy. MEL programs typically perform research, provide measurement services, and/or accelerate the development of standards.

MEL serves those U.S. manufacturing sectors that are considered to be within the scope of discrete-part manufacturing, and the aerospace industry is one of the two largest sectors of discrete-part manufacturing. In fulfilling its mission of satisfying the measurements and standards needs of the U.S. discrete-parts manufacturers in dimensional and mechanical metrology and in advanced manufacturing technology, MEL strives to promote a healthy U.S. aerospace manufacturing economy by solving tomorrow's measurement and standards problems today.

MEL programs focus their activities within the context of the following primary technology domains:

- Dimensional and mechanical metrology
- Manufacturing processes and equipment
- Systems integration and interoperability

MEL also places priorities on how and where it can best leverage its resources and produce significant outcomes for the U.S. society and economy. As such, MEL attempts to focus particular attention on working with, anticipating the needs of, and providing quality solutions to the problems of U.S. discrete-parts manufacturers. Two discrete manufacturing sectors represent a large impact on the U.S. economy: aerospace and automobile. MEL programs are directly relevant to and being worked in partnership with these two sectors.

The table on the following pages provides a listing of the year 2001 MEL programs that are either currently working in partnership with the aerospace industry, or are focusing on issues that are directly relevant to the industry. For each of these programs, which are

listed in the table in the order in which they were described in the body of this text, a note is provided that briefly describes the nature of the MEL/industry relationship.

MEL Program Relationships with the Aerospace Industry

Program	Notes on Relationship
Engineering Metrology	• Disseminates traceability to the SI unit of length in mid-range scales to U.S. aerospace manufacturers and their suppliers on a broad basis • Provides critical NMI services that serve as the metrological anchor of the length portion of aerospace manufacturing quality assurance systems
Large Scale Metrology	• Provides tools needed by U.S. aerospace manufacturers and their suppliers to reduce cost and improve measurement uncertainties associated with quality assurance systems involving large-scale metrology applications such as large coordinate measuring systems
Mechanical Metrology	• Disseminates tracebability to the SI unit of mass and derived units of force, acceleration, sound pressure, and ultrasonic power to U.S. aerospace manufacturers and their suppliers on a broad basis • Provides critical NMI services that serve as the metrological anchor of the mechanical portion of aerospace manufacturing quality assurance systems

Program	Notes on Relationship
Shop Floor as a National Measurement Institute	• Provides tools, methodologies, and standards needed by U.S. aerospace manufacturers to make traceable measurements on their shop floors, thus allowing manufacturers to meet contractual requirements for "new traceability" of dimensional measurements
Surface Metrology	• Delivers measurement services in surface and microform metrology that industry requires, specifically providing calibrations and services that support surface metrology and scanned probe microscopy • Works with NASA in the development of an optics metrology laboratory and capability for NASA optics
Metrology and Smart Sensor Systems for Manufacturing Equipment	• Works with aerospace manufacturers to develop metrology and standards required to improve the performance of their manufacturing equipment, especially machine tools, and monitor manufacturing equipment status to reduce unscheduled machine down time
Predictive Process Engineering	• Works with aerospace manufacturers to develop process models, process metrology, and process standards needed to achieve feed-forward manufacturing resulting in "first part correct" production
Intelligent Open Architecture Control of Manufacturing Systems	• Works with industry consortia and standards committees to provide standards and test methods for the control of aerospace manufacturing equipment – machine tools, robots, metrology systems – that are needed to achieve seamless flow of manufacturing data

Program	Notes on Relationship
Manufacturing Enterprise Integration	• Develops parameters, tests, and testbeds relating to aerospace manufacturing supply chains that help measure the quality and fitness of ontologies and mediators • Provides a foundation for new measurements and standards to enable on-the-fly, self-integration of manufacturing B2B software applications using intelligent agents and shared semantics, thus eliminating the need for interface specifications
Manufacturing Simulation and Visualization	• Works with simulation software vendors who supply to the aerospace industry to make the benefits of discrete-event manufacturing simulation affordable to manufacturers • Focuses on reducing the time and cost of model development and simulation system integration through the identification, specification, prototyping, testing, and evaluation of data interfaces and methods for integrating manufacturing simulation and visualization applications with each other and with other manufacturing software used by aerospace manufacturers
Product Engineering	• Works with aerospace manufacturers to develop interoperability protocols and knowledge representation schemes for CAD systems

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[2] "U.S. Industry and Trade Outlook 2000," U.S. Department of Commerce International Trade Administration and the McGraw-Hill Companies, National Technical Information Service, Springfield, VA, May 2000.